PRELIMINARY RESULTS OF THE VERIFICATION OF OFFSHORE OIL SPILL CONTAINMENT BOOM PERFORMANCE EVALUATION PROTOCOL[1]

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INTRODUCTION

An oil spill boom is a floating wall used to contain oil or other pollutants that float on water. Consisting of a floatation section and a skirt attached below, a boom may be subjected to all of the conditions water surfaces are known to present. The forces from fluid currents, waves, and turbulence each make booms less and less effective for collecting or containing the floating layer.

Over the past twenty years a number of parameters have been studied to evaluate boom performance. In 1969 Lehr and Scherer divided the parameters affecting boom performance into four major groups; they were: physical properties of the boom, hydrodynamic properties, mooring conditions and environmental conditions. These major groups had a total of twenty seven parameters iclud-ing such qualities as the tensile and shear moduli.[1] Also in 1969, Wicks specified the parameters that are significant to the interaction of floating oil and the water it is floating on.[2] Both Environment Canada,[3] the U.S. Environmental Protection Agency, Minerals Management Service, and other OHMSETT Inter-agency Technical Committee member organizations have been seeking ways to quantify boom performance. Data collected since 1975 at the U.S. EPA - OHMSETT Facility have been reported in terms of tow speeds at first oil loss and gross oil loss. In addition, booms were tested for stability in water currents, calm water,

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sinsusoidal waves and harbour chop. Parameters reported by the OHMSETT personnel over the years have not specifically addressed the boom behavior in engineering terms that relate to boom construction.[4] Moduli and moments of inertia of a booom, as suggested by Lehr and Scherer, are begining to enter the evaluation scheme in the symptomatic manifestation called wave conformance.

An effort is now underway to systematize the testing of oil spill booms. Using the knowledge gained over the past twenty years a "Test Protocol for the Evaluation of Oil-Spill Containment Barriers" is being established.[5] The required testing is designed as two separate phases. The first phase is a series of tests to be conducted in a test tank. These tests document the oil holding abilities of the barrier. The second phase designates open-water testing. These tests measure the wave conformance capabilities of the barrier. Open water tests do not use oil although the tests reported here do involve oil being spilled incidental to the tests.

The present discussion is about the reaction of a boom to water surface wave motion and the resulting deterioration of oil holding ability; and specifically, about testing an oil boom at the OHMSETT Facility and in the open ocean off Newfoundland.

BASIC ELEMENTS

Water, Wind, Waves, and Currents

Waves in the open ocean result from combined driving forces. Waves are initially created by wind blowing across the surface of water. The size of the waves depends on how long in time (duration), how great an uninterrupted distance across the water (fetch) and how strong the wind blows. Waves that are created by a wind can out run the wind that caused them. These waves become known as "swell". The swell from one weather system then combines with the wind driven waters of another weather system creating a mixture of wave patterns.

Accurately observing, measuring and reporting the wave condition in open water therefore requires separation of the wave pattern into its component parts. Wave records often take the form of a height measurement (the water surface) over time at a stationary point. In order to make the wave record meaningful (in terms that can be used to engineer or evaluate), frequency spectrum are calculated using Fourier analysis to describe the sea surface's wave components. Such analyses produce a frequency based rather than a time based relationship with the amplitude of the waves.

Repeated measurements of the sea surface height at one location over time results in a collection of amplitude spectra, each spectra possibly different from the others. A sea condition that is consistent enough to warrant a characteristic spectrum is assigned that character by determining the variance of the amplitude spectra. Variance involves the square of the amplitude. Since the square of the amplitude is proportional to the energy, one way of regarding the variance of the amplitudes of the Fourier components is to call it the energy spectrum.[6]

The surface currents that can be induced by winds as well as the orbital "currents" within waves are major causes of lost oil when oil booms are used to contain floating pollutants. Two parameters used to evaluate a boom in moving bodies of water are: first loss tow speed and critical tow speed. First loss tow speed is the relative water current velocity between a boom holding oil and a water body when oil droplets first shear from the contained oil mass and escape beneath the skirt of the boom. The critical tow speed is the relative current velocity between the boom and water when the boom either submerges or planes Table 1 lists the ranges of these to parameters (in Meters per Minute) measured at the USEPA-OHMSETT Facility between 1975 and 1982. The effect of waves in reducing performance is significant. Harbour chop (random sea) reduces the critical tow speed by 60% from calm water conditions according to this historical perspective.

TABLE 1. 1975-1982 OHMSETT DATA RANGES FOR THE TWO MOST IMPORTANT MEASUREMENTS OF BOOM STABILITY

	CALM	WAVES REGULAR*	WAVES HARBOUR CHOP
Critical Tow speed (M/sec)	0.5 - 1.91	0 - 1.14	0 - .76
1st Loss Tow Speed m/sec	0.1 - .57	0 - .56	0 - .38

*Regular means sinusoidal, a monochromatic wave used to measure responses to specific waves

The Interaction of Booms, Waves, and Oil

In July of 1981 and June of 1984, tests were run on what was then known as the Albany Oil Fence (presently the Globe Oil Fence). This oil barrier was not selected for any specific characteristics other than it was available and had a high tension modulus. The 1981 tests established a Boom Loss Measurement Protocol.[7] Figure 1 graphically displays the functional relationship between the loss rate from the boom and the tow speed through calm water.

In 1984 this same style boom was used to evaluate instrumentation designed for measuring boom motion as a response to sea surface wave motion. The study paralleled the type of analysis that goes into the determination of a response amplitude operator (RAO) for ships.

The response a ship exhibits to the wave motion of an "...irregular sea can be represented by a linear summation of its responses to the components of the sea." "...The significance of the principle of superposition [the linear summation] is that if

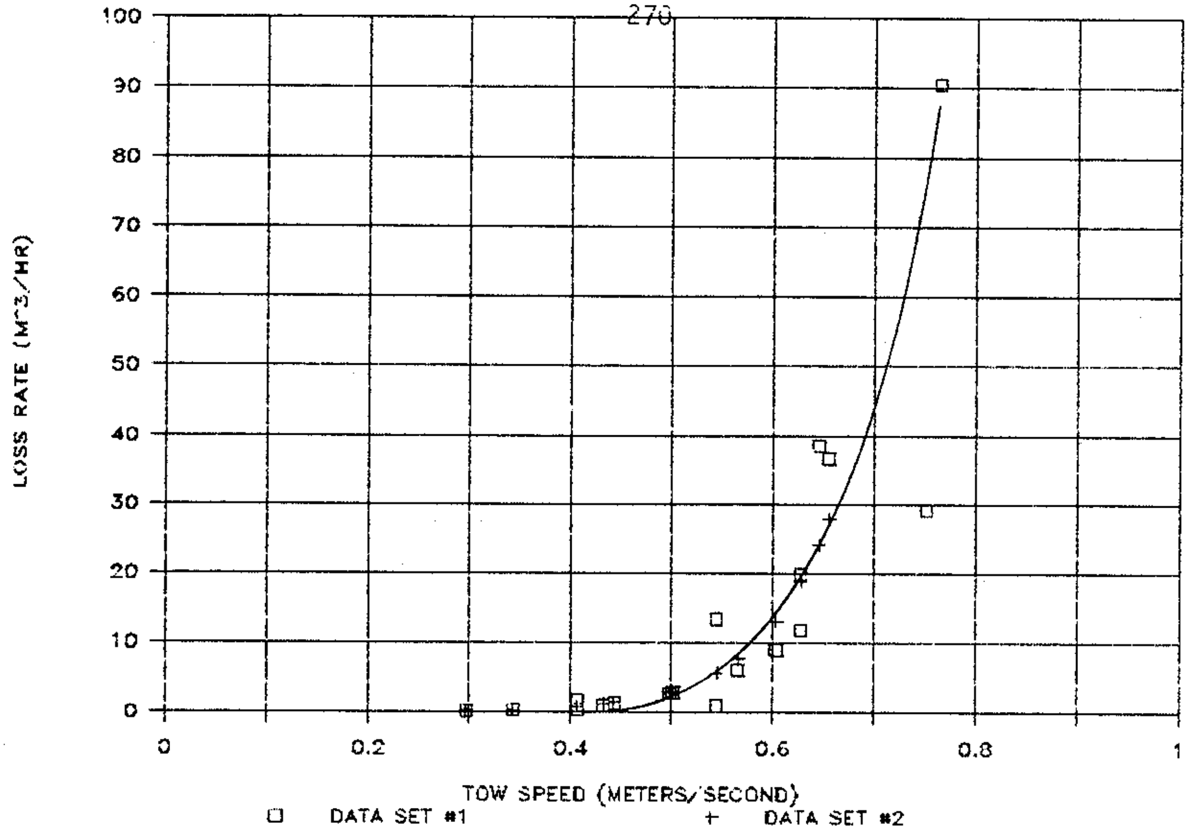

Figure 1. Oil loss measurements made at the EPA-OHMSETT facility. The device was an "Albany Oil Fence"

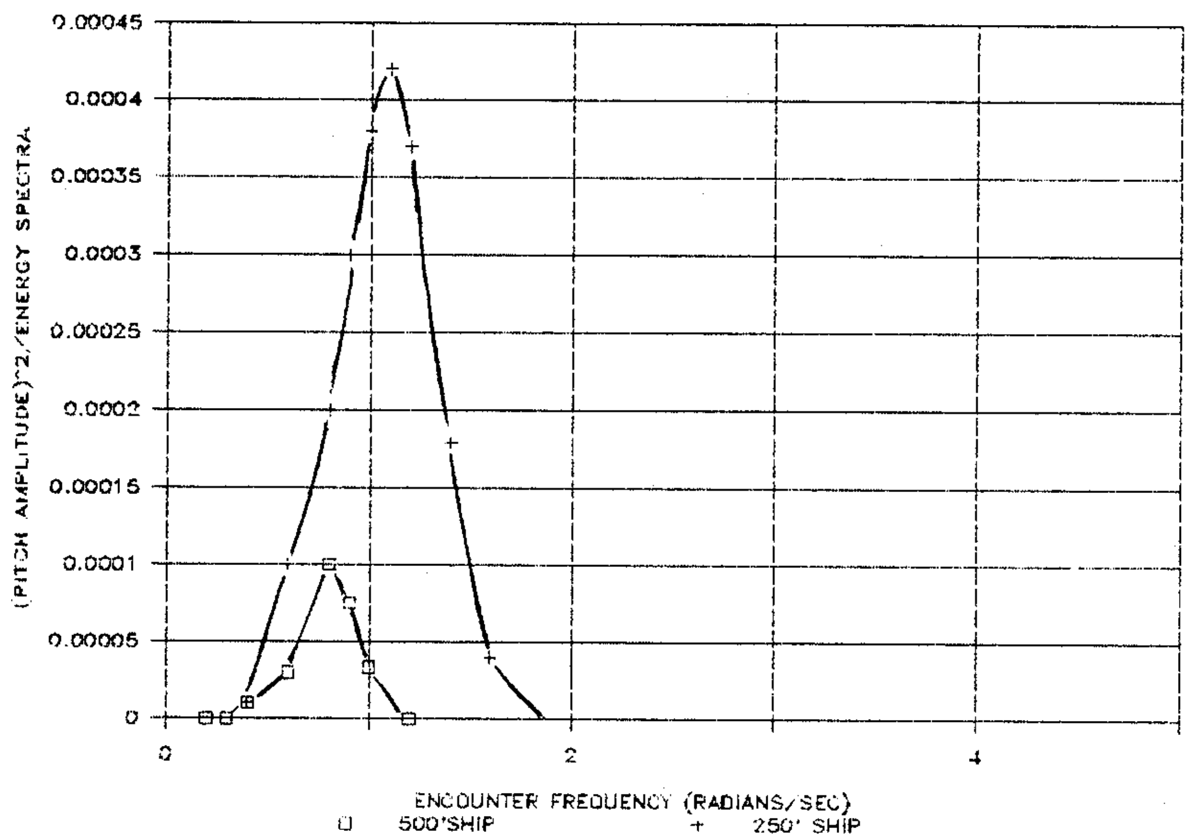

Figure 2. Examples of pitch response amplitude operators for two ships.

we know the ships response to the component waves as determined either by calculation or by model tests, we can predict the behavior of a ship in any actual or imagined seaway, described by its energy spectrum".[8] As discussed above the seaways energy spectrum is the squared amplitude of waves that exists over the frequency range. A convenient way to represent the response of a ship to a wave is to square the amplitude of the response and determine the ratio of the squared response amplitude to the wave energy at the specific frequency response amplitude operator. Figure 2 is a graph of response amplitude operators for two ships (reference 8). The encounter frequency ω_e is in radians per second ($\omega_e = 0.4$ is equivalent to a wave period of 15.7 seconds).

By applying a similar approach (the emphasis is on similar) to the motion of an Oil Fence in monochromatic wave forms we determined a boom RAO (BRAO). In this case, the amplitude of the Fence was the depth of the skirt below the surface of the water as measured by pressure. By definition zero amplitude was the pressure defined depth (P) at rest in calm water. The water surface amplitude (W) was measured using an ultrasonic transponder mounted above the surface of the water.

The boom was towed in a catenary configuration. Strip chart traces of the measured amplitudes over time were used to obtain P and W. See Figure 3. From these values we made a plot of $(P/W)^2$ versus the encounter frequency. The plot, appearing in Figure 4, demonstrates that the Oil Fence starts to overtly react (not conform) to the water surface at frequencies above 2 rad/sec. In terms of wave period that is equivalent to three seconds and shorter.

Open Water Verification of the Tank Testing

The four basic measurements required to verify the tank tests and in part verify the Boom Test Protocol are: tow speed, oil loss, sea spectrum, and boom response. In the trials tow speed was measured using wood chips and a stopwatch along side one of the tow vessels. Oil loss was visually estimated. Unfortunately during the test a twist developed in the boom causing a gross oil loss. Also unfortunately, sea spectrum data was to have been electronically generated. However, the system failed to function. Pressure sensed boom response data was digitally recorded via data loggers.

The tow speed measurements were made during those times when the tow vessels were properly aligned and towing the boom within the prescribed tow speeds. These values varied between .24 and .55 meters/sec. Predicted oil loss from Figure 1 at these speeds is zero. Yet significant oil loss was occurring as reported by observers even before the twist developed. It is quite probable that the oil was lost during the maneuvering required to establish, intermittently proper alignment and speed. One vessel was designated to hold course while the second vessel would do all the maneuvering. One of the test crew, who has twelve years experience in small vessels in the open ocean, and was on the maneuvering vessel, estimates that speeds up to 2.5 meters/sec

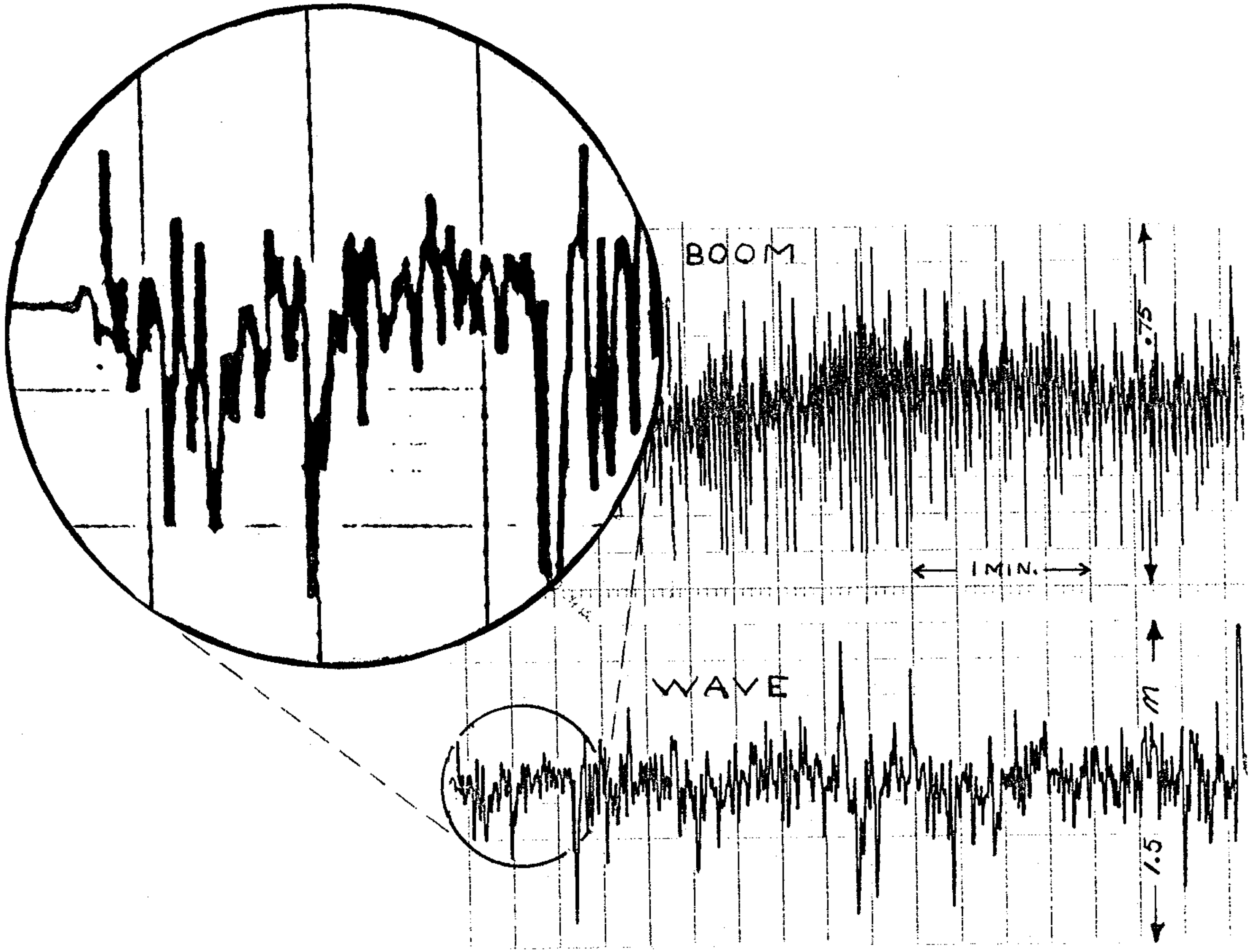

Figure 3. Trace of a boom response to a wave as sensed by a pressure gauge mounted on the bottom of the boom "skirt."

were achieved.

The sea conditions have been reported by visual observations from several observers, both in the smaller tow vessels and in the larger support vessels. The sea consisted of a swell, 1.5 to 2 meters in height at 5 to 7 sec periods (1.25 to 0.9 rad/sea) and wind driven waves, 0.5 to 1.0 meters in height at 3 second periods (2.1 rad/sec). According to the RAO, as defined in Figure 4, the boom should show little overt response to these

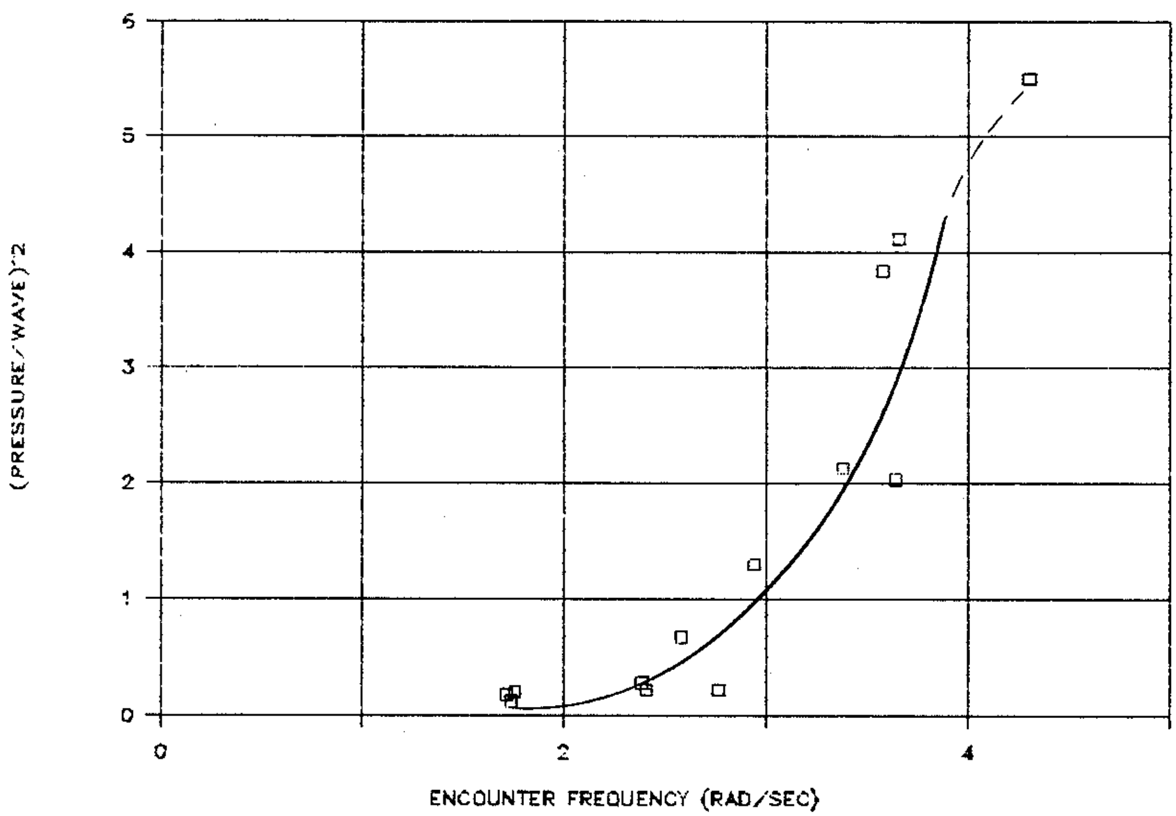

Figure 4. "Boom Response Amplitude Operator", Note the difference in response frequency in Fig. 2 also the y-axis should be noted as different.

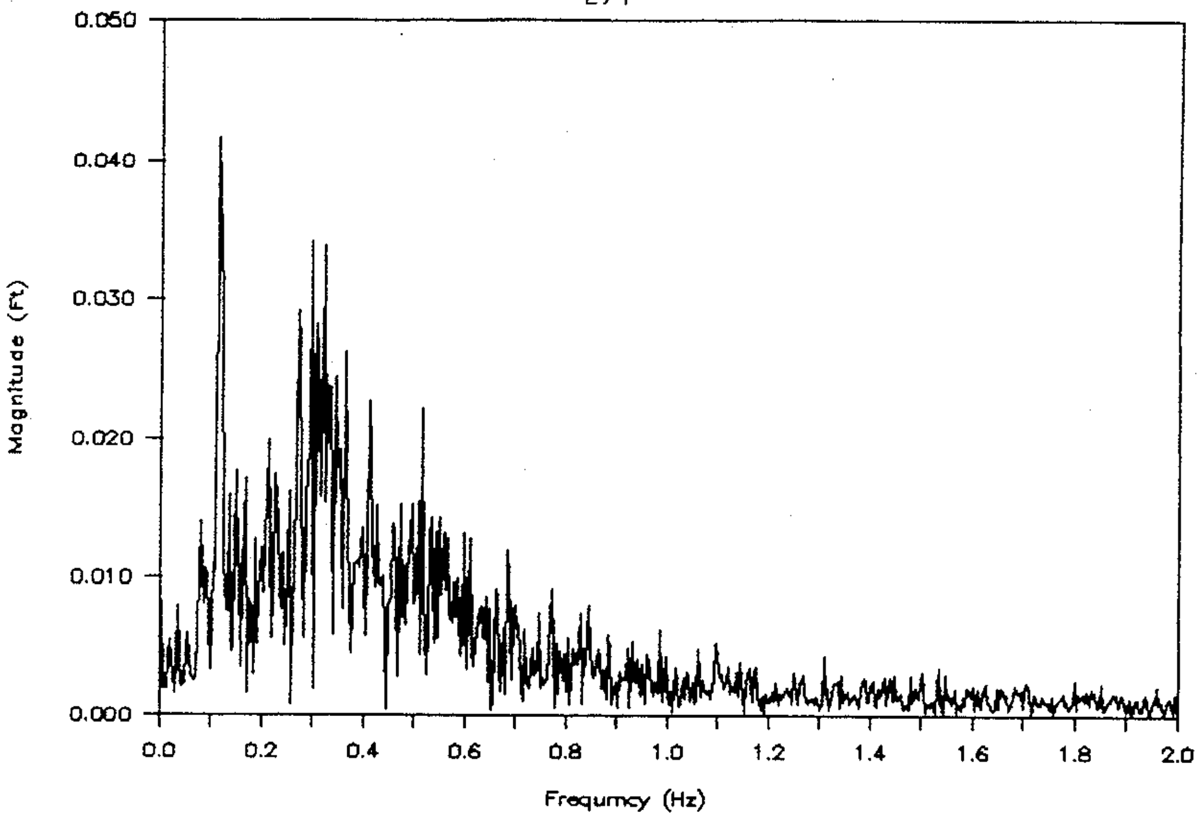

Figure 5. Example of amplitude frequency spectrum for 1987 off-shore boom test.

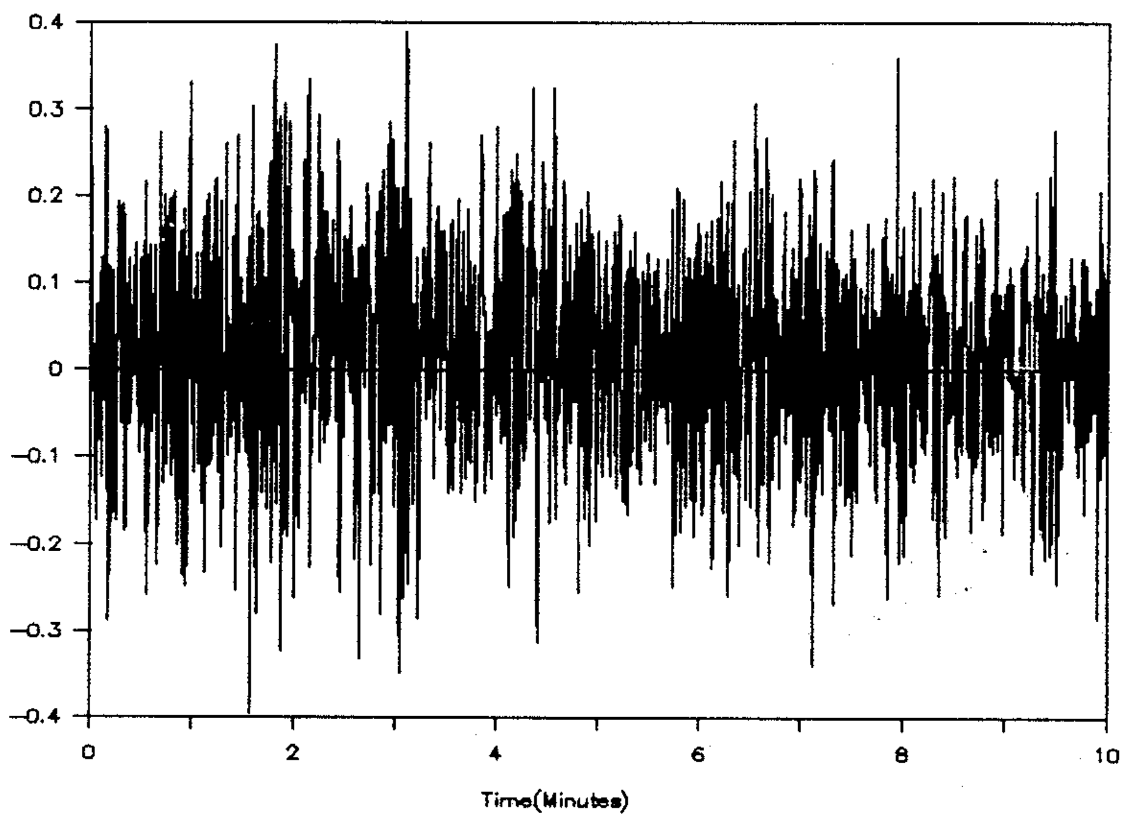

Figure 6. Example of boom amplitude time tracing for the 1987 off-shore boom test.

waves. In other words, the boom should be conforming to the waves.

A graphical printout of a Fourier transformed time record taken during the test shows almost noise level response from the boom as sensed by pressure at the bottom of the skirt. See Figure 5. The ordinate in Figure 5 (the y axis) is presented in feet. The highest value is 0.04 ft. which is 1.2 centimeters at 0.75 rad/sec. The cumulative amplitude of the boom response was between 12 and 24 centimeters according to the "pressure defined" wave record (See Figure 6). Oil in the boom also contributed to the booms conformance by reducing the high frequency components as oil will do. The oils effect can be seen in the photo presented in Figure 7. Notice the loss of chop at the boom apex in the foreground.

Conclusions

The Boom Test Protocol element involving BRAO and wave conformance was verified for the sea conditions encountered during the sea trials. Although the Protocol does not call for the spilling of oil at sea, this "spill of opportunity" was used to verify the tank testing of first loss tow speed. This aspect was not verified, due primarily to the maneuvering difficulties created by the sea conditions that caused boats to respond but not the boom.

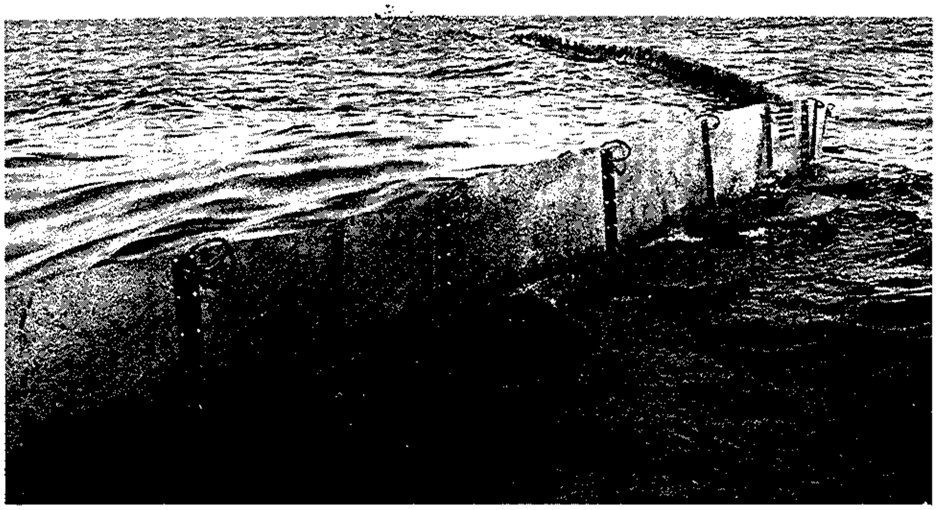

Figure 7. Sea surface condition at the boom with oil present.

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